FERMILAB-Pub-80/89-THY
October 1980

The Importance of the $K\eta$ and $K\eta'$ Decay Modes in Understanding Charmed and Other Meson Decays

HARRY J. LIPKIN*
Fermi National Accelerator Laboratory, Batavia, Illinois 60510
and
Argonne National Laboratory, Argonne, Illinois 60439

(Received

ABSTRACT

The $D^0 \to \bar{K}^0\eta$ decay mode is shown to be suppressed by a large factor insensitive to $\eta - \eta'$ mixing and SU(3) symmetry breaking in all diagrams where the η is produced via the $d\bar{d}$ and $s\bar{s}$ components, but to be roughly equal to the $\bar{K}^0\pi^0$ and $\bar{K}^0\eta'$ when produced via the $u\bar{u}$ component. The relative decay rates to $\bar{K}^0\eta$, $\bar{K}^0\eta'$ and $\bar{K}^0\pi^0$ distinguish between models producing the additional $q\bar{q}$ pair in weak or strong vertices.

---

*On leave from Department of Physics, Weizmann Institute of Science, Rehovot, Israel.

PACS Category Nos.: 13.25.+m, 12.30.-s

Nonleptonic decays of charmed mesons appear to be complicated and not to fit any simple model.[1-10] Attempts to understand these decays either by symmetries or dynamics involve fitting a number of branching ratios with several independent amplitudes, either with different symmetry properties or arising from different diagrams. Assumptions that any one particular symmetry amplitude or diagram is dominant have not been successful.

An alternative approach is to look for particular decay channels which can distinguish between two types of contributions and can therefore narrow down the search for the right set of contributing amplitudes. The η and η' states provide useful information in this approach, because they have the same quark constituents and differ only by a relative phase. Diagrams in which this relative phase plays a crucial role predict suppression of one channel or another. In the particular case of D^o decays there is a simple division of all possible mechanisms into two classes which produce the η or η' via the $u\bar{u}$ component or the $d\bar{d}$ and $s\bar{s}$ components. The $\bar{K}^o\eta$ decay is strongly suppressed in the latter and not in the former.

Consider the decays $D^o \to \bar{K}^o P^o$, where P^o is a neutral pseudoscalar meson, π^o, η or η'. There is one quark-antiquark pair in the initial state and two pairs in the final state. There are only two mechanisms for the creation of the additional pair, one weak and one strong:

1. <u>The additional pair is created directly in the weak decay of the charmed quark $c \to su\bar{d}$</u>, with no further pair annihilation and recreation in final state interactions. In this case the final state has the quark constituents $(s\bar{d})$ $(u\bar{u})$ and the neutral pseudoscalar P^o is created via its $u\bar{u}$ component. The $\bar{K}^o\eta$, $\bar{K}^o\eta'$ and $\bar{K}^o\pi^o$ are created with roughly equal amplitudes, corrected by phase space and a factor of $\sqrt{2}$ enhancing the $\bar{K}^o\pi^o$ mode.

2. The additional pair is created by a strong gluon. This includes both the diagrams where the weak transition leads to a single $q\bar{q}$ state and the additional pair is created by gluons and the diagrams where a $u\bar{u}$ pair created in a weak transition via the mechanism (1) above is annihilated into one or more gluons and a new $q\bar{q}$ pair is created. The gluons create $u\bar{u}$, $d\bar{d}$ and $s\bar{s}$ pairs with roughly equal amplitudes (corrections for flavor SU(3) symmetry breaking are discussed below), but only the $d\bar{d}$ and $s\bar{s}$ contributions are allowed by the OZI rule to contribute to the $\bar{K}^oP^o$ final state. The relative phases of these two contributions are such that they interfere constructively for the $\bar{K}^o\eta'$ mode and destructively for the $\bar{K}^o\eta$ mode. Thus the $\bar{K}^o\eta$ decay mode is strongly suppressed relative to the $\bar{K}^o\eta'$.

A measurement of the ratio of the decays $D^o \to \bar{K}^o\eta$ and $D^o \to \bar{K}^o\eta'$ should therefore determine whether the dominant mechanism of the decay is of type 1 (weak production of the additional pair) or type 2 (strong production of the additional pair). This information can provide important clues and constraints on models which attempt to describe the details of the decay process. The qualitative argument given above is very insensitive to effects of SU(3) breaking and η-η' mixing which normally plague predictions of this kind. We now consider this process quantitatively in detail.

The transition amplitude for the mechanism 1 can be written

$$\langle \bar{K}^oP^o|W_1|D^o\rangle = \langle P^o|P_u\rangle\langle \bar{K}^oP_u|W_1|D^o\rangle \quad , \tag{1}$$

where P_u, P_d and P_s denote the neutral pseudoscalar meson states with the quark constituents $u\bar{u}$, $d\bar{d}$ and $s\bar{s}$ respectively. Equation (1) expresses the observation that transitions via this mechanism must go by the $u\bar{u}$ state.

The transition amplitude for the mechanism 2 can be written

$$\langle P_1P_2|W_2|D^o\rangle = \langle P_1P_2|G|(s\bar{d})\rangle\langle(s\bar{d})|W|D^o\rangle \tag{2}$$

where P_1 and P_2 are any two pseudoscalar mesons, charged or neutral, G is the operator which denotes the transition from a single $q\bar{q}$ pair to two pairs by strong gluon interactions, and W describes the weak transition from the initial D^o state to an intermediate $(s\bar{d})$ state, including effects of strong gluon interactions. Equation (2) expresses the essential feature of mechanism 2; namely that the transition proceeds via an intermediate $q\bar{q}$ state which must be $s\bar{d}$ to conserve charge and strangeness in the strong transition to the final state. The flavor dependence of the gluon matrix element is given by

$$\langle(s\bar{u})(u\bar{d})|G|(s\bar{d})\rangle = \langle(s\bar{d})(d\bar{d})|G|(s\bar{d})\rangle = (1/\xi)\langle(s\bar{s})(s\bar{d})|G|(s\bar{d})\rangle \quad , \tag{3}$$

where ξ is an SU(3)-breaking parameter which is unity in the flavor SU(3) limit and is generally less than unity.[11-12] We consider amplitudes in which the additional $q\bar{q}$ pair produced is split between the two final mesons, in accordance with the OZI rule. Thus the $u\bar{u}$ amplitude contributes only to charged decay modes.

The gluon matrix element for the physical meson final states is then given by

$$\langle P_1P_2|G|(s\bar{d})\rangle = \sum_{q=u,d,s} \langle P_1|(s\bar{q})\rangle\langle P_2|(q\bar{d})\rangle\langle(s\bar{q})(q\bar{d})|G|(s\bar{d})\rangle \quad . \tag{4}$$

The overlaps between the quark states and the pseudoscalar mesons are assumed to be simply related; i.e. all mesons in the pseudoscalar nonet are assumed to have the same spatial wave functions,

$$\langle K^-|(s\bar{u})\rangle = \langle\bar{K}^o|(s\bar{d})\rangle = \langle P_s|(s\bar{s})\rangle = \langle\pi^-|(u\bar{d})\rangle = \langle P_d|(d\bar{d})\rangle = \langle P_u|(u\bar{u})\rangle. \tag{5}$$

The neutral mesons are related to the P_u, P_s and P_d states by the usual expressions,

$$|\pi^o\rangle = (1/\sqrt{2})|P_u - P_d\rangle \tag{6a}$$

$$|\eta_8\rangle = (1/\sqrt{6})|P_u + P_d - 2P_s\rangle \tag{6b}$$

$$|\eta_1\rangle = (1/\sqrt{3})|P_u + P_d + P_s\rangle \tag{6c}$$

$$|\eta\rangle = (1/2)|P_u + P_d - \sqrt{2}P_s\rangle \tag{7a}$$

$$|\eta'\rangle = (1/2)|P_u + P_d + \sqrt{2}P_s\rangle \tag{7b}$$

where η_8 and η_1 are the SU(3) octet and singlet states and Isgur's mixing angle[13] has been used to define the physical η and η'. Our results are insensitive to the exact value of this mixing angle.

Substituting eqs. (3-7) into eqs. (1) and (2) gives the following results:

$$\langle\bar{K}^o\pi^o|W_1|D^o\rangle = \sqrt{3}\langle\bar{K}^o\eta_8|W_1|D^o\rangle = (\sqrt{3/2})\langle\bar{K}^o\eta_1|W_1|D^o\rangle \tag{8a}$$

$$\langle\bar{K}^o\pi^o|W_1|D^o\rangle = \sqrt{2}\langle\bar{K}^o\eta|W_1|D^o\rangle = \sqrt{2}\langle\bar{K}^o\eta'|W_1|D^o\rangle \quad . \tag{8b}$$

In the SU(3) limit, $\xi = 1$,

$$-\langle\bar{K}^o\pi^o|W_2|D^o\rangle = \sqrt{3}\langle\bar{K}^o\eta_8|W_2|D^o\rangle = (\sqrt{3/8})\langle\bar{K}^o\eta_1|W_1|D^o\rangle \quad . \tag{9a}$$

In general, for arbitrary values of ξ,

$$-\langle \bar{K}^o \pi^o | W_2 | D^o \rangle = [\sqrt{2}/(1-\sqrt{2}\xi)] \langle \bar{K}^o \eta | W_2 | D^o \rangle = [\sqrt{2}/(1+\sqrt{2}\xi)] \langle \bar{K}^o \eta' | W_2 | D^o \rangle . \quad (9b)$$

Equations (8a) and (8b) show that the transitions to the $\bar{K}^o\pi^o$, $\bar{K}^o\eta$ and $\bar{K}^o\eta'$ states via mechanism (1) are roughly equal and insensitive to the mixing angle. However, eqs. (9a) and (9b) show that the transition via mechanism (2) to the $\bar{K}^o\eta$ final state is strongly suppressed over a wide range of mixing angles and SU(3) symmetry breaking. The ratio of the reduced transition probabilities (with phase space factored out) for the $\bar{K}\eta$ and $\bar{K}\eta'$ transitions is 1/8 in the SU(3) limit with no mixing. Both mixing and SU(3) breaking make the suppression stronger. With the Isgur mixing angle, the suppression factor is $[(1-\sqrt{2}\xi)/(1+\sqrt{2}\xi)]^2$. This is less than 1/9 for all values of ξ between $\sqrt{2}$ and $1/\sqrt{8}$. Thus the $\bar{K}\eta$ decay mode is suppressed at least by a factor of 9 relative to $\bar{K}\eta'$ when the probability of producing an $(s\bar{s})$ pair from the vacuum is anywhere between double and 1/8 of the probability of producing a $(d\bar{d})$ pair.

Thus a measurement of the $\bar{K}^o\pi^o$, $\bar{K}^o\eta$ and $\bar{K}^o\eta'$ branching ratios in the D^o decay should be able to distinguish between the two mechanisms.[14] Even an upper limit on the ratio of unobserved $\bar{K}^o\eta$ decays to $\bar{K}^o\pi^o$ decays is significant. It rules out mechanism (1) if it is well below the prediction (8a) of 1/3.

This approach can be applied to any process which decays to $\bar{K}^oP^o$ or $\bar{K}^{*o}P^o$ states via an intermediate $s\bar{d}$ state. The results are a straightforward generalization of the well-known SU(3) predictions that the $K\eta_1$ and $K^*\eta_1$ decays are forbidden in transitions with F-type coupling and the $K\eta_8$ and $K^*\eta_8$ decays are suppressed by a factor of 3 relative to the π^o decays with D-type coupling and suppressed by a factor of 8 relative to the η' decays if the OZI rule is assumed in addition to D coupling. When SU(3) breaking and mixing described by Isgur's angle are included, the results analogous to eqs. (9) are:

$$-\langle \bar{K}^{o}\pi^{o}|G|(s\bar{d})\rangle = [\sqrt{3}/(1 \mp 2\xi)]\langle \bar{K}^{o}\eta_{8}|G|(s\bar{d})\rangle = [(\sqrt{3/2})/(1 \pm \xi)]\langle \bar{K}^{o}\eta_{1}|G|(s\bar{d})\rangle \quad (10a)$$

$$-\langle K^{o}\pi^{o}|G|(s\bar{d})\rangle = [\sqrt{2}/(1 \mp \sqrt{2}\xi)]\langle \bar{K}^{o}\eta|G|(sd)\rangle = [\sqrt{2}/(1 \pm \sqrt{2}\xi)]\langle K^{o}\eta'|G|(sd)\rangle \quad (10b)$$

where the upper sign is used for transitions described by D-type coupling and the lower sign for F-type. Whether the coupling is D or F depends in this case upon whether the amplitude is symmetric or antisymmetric under the interchange of the two final state mesons. In the s-wave D^{o} decays (9), the amplitude is symmetric and the upper sign of (10) is seen to be in agreement with the results (9). The results (10) hold for any $(s\bar{d})$ intermediate state and the K^{o} can be replaced by any K^{*} resonance or other state with the same flavor quantum numbers.

If the three-body decays $D^{o} \to \bar{K}\pi P^{o}$ are dominated by the W_2 mechanism, then the $K^{*}(890)\eta$ channel should be enhanced and the $K^{*}(890)\eta'$ suppressed (but probably unobservable because of low phase space). However, for an s-wave $\bar{K}\pi$ system the $\bar{K}\pi\eta$ mode is suppressed and the $\bar{K}\pi\eta'$ enhanced. Thus if both decays are observed, the Dalitz plots for the two should be very different.

Application of these results to decays of strong K^{*} resonances may be of interest. Precise measurements of the suppression factors may give information on the mixing angles and SU(3) breaking.

REFERENCES

[1] For a general review see C. Quigg, Z. Physik C4, 55 (1980).

[2] M. Suzuki, Phys. Lett. 85B, 91 (1979) and Phys. Rev. Letters 43, 818 (1979); V. Barger and S. Pakvasa, Phys. Rev. Lett. 42, 1589 (1979); Ling-Lie Wang and F. Wilczek, Phys. Rev. Letters 43, 816 (1979).

[3] N. Deshpande, M. Gronau and D. Sutherland, Phys. Lett. 90B, 431 (1980); H. Fritzsch, Phys. Lett. 86B, 343 (1979); H. Fritzsch and P. Minkowski, Phys. Lett. 90B, 455 (1980).

[4] N. Cabibbo and L. Maiani, Phys. Lett. 73B, 418 (1978); D. Fakirov and B. Stech, Nucl. Phys. B133, 315 (1978); S.P. Rosen, Phys. Lett. 89B, 246 (1980).

[5] H.J. Lipkin, Phys. Rev. Letters 44, 710 (1980); S.P. Rosen, Phys. Rev. Letters 44, 41 (1980).

[6] J.F. Donoghue and B.R. Holstein, Phys. Rev. D21, 1334 (1980).

[7] M.B. Einhorn and C. Quigg, Phys. Rev. D12, 2015 (1975).

[8] R.L. Kingsley, S.B. Treiman, F. Wilczek, and A. Zee, Phys. Rev. D11, 1919 (1975).

[9] J.F. Donoghue and L. Wolfenstein, Phys. Rev. D15, 3341 (1977).

[10] K. Jagannathan and V.S. Mathur, Phys. Rev. D21, 3165 (1980) and Nuclear Physics B171, 78 (1980).

[11] H. Fritzsch and J.D. Jackson, Phys. Lett. 66B, 365 (1977).

[12] H.J. Lipkin, in: Deeper pathways in high energy physics, Proc. Orbis Scientiae (Coral Gables, 1977) eds. B. Kursunoglu, A. Perlmutter and L.F. Scott (Plenum, New York, 1977), p. 567.

[13] Nathan Isgur, Phys. Rev. D12, 3770 (1975).

[14] Thomas G. Rizzo and Ling-Lie Wang, Brookhaven preprint BNL-27950, have recently classified charm decays by quark diagrams. Their amplitudes b and c correspond exactly to transitions denoted here by W_1 and W_2. They also give the relations between these amplitudes and the SU(3) amplitudes of refs. 1 and 2. Their remaining amplitudes a, d, e and f do not contribute to Cabibbo favored neutral decays and are not relevant to this discussion. In their terminology, the $\bar{K}^o\eta$ decay is strongly suppressed if the c amplitude is dominant. Thus the $\bar{K}^o\eta$ branching ratio measures directly the strength of the b amplitude.

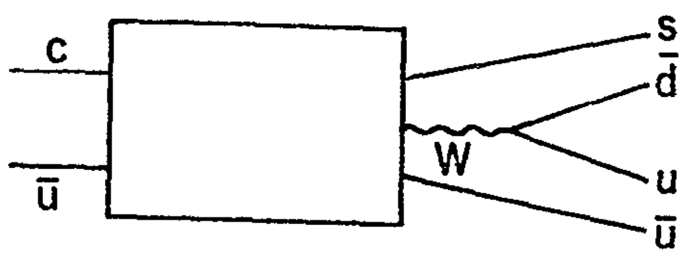

Fig. 1

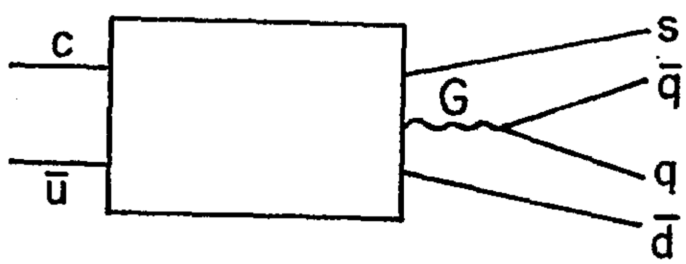

Fig. 2